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ABSTRACT

This monograph is one in a series of analytical reports presenting findings from the National Science Foundation's 1989-90 National Survey of Academic Research Instruments and Instrumentation Needs. It describes recent national trends in academic research equipment and equipment needs in the fields of computer science and engineering. It also documents equipment trends in central academic computing facilities. The data were obtained from a sample of 55 universities statistically selected to represent all institutions with annual science/engineering research and development expenditures of $3 million or more. The analysis compares data obtained in 1989 to similar data collected from the same institutions in 1986 and 1983. Information about current needs and priorities refers to the year the survey was conducted; information about equipment amounts and expenditures refers to the year prior to the survey (i.e. 1988, 1985, 1982). The study is limited to research equipment originally costing $10,000 or more per system. Sections under the headings of computer science, academic computer centers, and engineering include some or all of the following information: (1) annual expenditures; (2) inventory size and composition; (3) department assessments; (4) sources of inventory funding; (5) equipment needs and priorities; and (6) institution profiles. A list of sampled institutions is appended. (KR)

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ACADEMIC RESEARCH EQUIPMENT IN COMPUTER SCIENCE, CENTRAL COMPUTER FACILITIES AND ENGINEERING: 1989

Bradford Chaney, Westat, Inc.
Kenneth Burgdorf, Westat, Inc.

Surveys of Science Resources Series
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At NSF, the survey was developed and guided by Judith F. Coakley, Senior Science Resources Analyst, Division of Science Resources Studies, Sciences and Engineering Activities Program (SEAP). Guidance and review were provided by William W. Ellis, Acting Director, Division of Science Resources Studies.

Paul Seder, NIH Office of Science Policy and Analysis, directed the National Institutes of Health components of the study.

The study also benefitted from the advice of an expert advisory panel. As well as providing many useful recommendations for the design and conduct of the study, several members of the current advisory panel made significant contributions to the development of the equipment classification taxonomy that is used in the data analysis. The members of this panel are named on the inside back cover of this report.

The burden of the study's extensive data collection activities was borne largely by the institution-appointed survey coordinators at the 55 sampled institutions, to whom we owe a special debt of gratitude. The institutions that participated in the survey are listed in Appendix A.

SUGGESTED CITATION

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HIGHLIGHTS

This monograph is one in a series of analytical reports presenting findings from the National Science Foundation's 1989-90 *National Survey of Academic Research Instruments and Instrumentation Needs*. It describes recent national trends in academic research equipment and equipment needs in the fields of computer science and engineering. It also documents equipment trends in central academic computing facilities. The data were obtained from a sample of 55 universities statistically selected to represent all institutions with annual science/engineering R&D expenditures of $3 million or more. The analysis compares data obtained in 1989 to similar data collected from the same institutions in 1986 and 1983. Information about current needs and priorities refers to the year the survey was conducted; information about equipment amounts and expenditures refers to the year prior to the survey (i.e., 1988, 1985, and 1982). The study is limited to research equipment originally costing $10,000 or more per system.

COMPUTER SCIENCE

- **Annual Equipment Purchases**. The period from 1982 to 1985 saw a proliferation of computer science departments and a marked increase in annual research equipment purchases, from $20 million in 1982 to $49 million in 1985. Research equipment purchases in 1988 leveled off to $45 million, slightly below the 1985 figure.

- **Accumulated Total Amount of Equipment**. The aggregate purchase price of all in-use research equipment in computer science more than doubled from 1982 ($50 million) to 1985 ($114 million). By the end of 1988, the accumulated total had increased further, to $168 million. The 1985-88 increase was a comparatively modest 47 percent, after adjustment for inflation, reflecting the recent stabilization in annual equipment purchases.

- **Perceptions**. Despite the slowed rate of equipment growth, three-fourths of all computer science department heads reported net increases in their amounts of research equipment in the 1986-89 period, and the percentage reporting that their researchers cannot perform critical experiments in their areas of interest due to inadequate equipment declined from 92 percent in 1983 to 59 percent in 1989. However, 85 percent of computer science department heads also reported that their instrumentation needs had increased over the 1986-89 period.

- **Types of Equipment**. In computer science, the greatest growth in the 1985-88 period was seen for equipment at the lower end of the study's price range. Specifically, networks and single-user workstations in the $10,000 to $49,999 range grew from 27 percent of the total 1985 investment to 35 percent by 1988. Overall, equipment systems costing $10,000 to $99,999 accounted for 62 percent of the aggregate investment in 1988, up from 51 percent in 1985.

- **Funding Sources**. Despite the growing prominence of single-user systems and networks at the lower end of the price spectrum, Federal funding support became increasingly focused on large systems. Thus, although the overall Federal share of the funding for computer science research equipment declined from 1985 (53 percent) to 1988 (42 percent), the Federal share for equipment in the $400,000 to $999,999 range increased markedly, from 23 percent in 1985 to 58 percent in 1988. The Department of Defense and NSF were the principal providers of this Federal support.

- **Needs**. This growing Federal focus on providing financial support for relatively high cost computer science research equipment seems consistent with the wishes of the user community. The percentage of computer science department heads who recommended that increased Federal support be concentrated on equipment in the $50,000 and over range grew from 24 percent in 1986 to 58 percent in 1989.

ACADEMIC COMPUTER CENTERS

- **Scope**. Most colleges and universities have a single, general-purpose academic computer center that is used at least partly for research. A few also have computer centers that are dedicated entirely to research use. Additionally, five NSF National Supercomputer Centers, which provide further computing resources for academic scientists and engineers, were in operation by the end of 1988.

- **Total Amount of Equipment**. The aggregate purchase price of the equipment in these central computing facilities more than doubled from 1982 ($423 million) to 1985 ($877 million). It grew at a slower pace over the next three years, increasing to $1.3 billion by the end of 1988, an inflation-adjusted increase of 37 percent from 1985 to 1988. Much of the overall growth from 1985 to 1988 was due to the NSF National Supercomputer Centers program, which expanded from $16 million of on-line equipment in 1985 to $247 million in 1988. During the same period, other academic computer centers grew only 13 percent.

ENGINEERING

- **Annual Equipment Purchases**. Controlling for inflation, annual purchases of engineering research equipment increased by 33 percent from 1985 ($174 million) to 1988 ($251 million). Similar growth occurred during the previous three-year period.

- **Accumulated Total Amount of Equipment**. The aggregate purchase price of all in-use engineering research equipment increased by 86 percent, in constant dollars, from 1985 ($435 million) to 1988 ($884 million).

- **Subfields**. Electrical engineering was the subfield with the largest amount of research equipment in 1988 ($249 million), and it had a relatively high rate of growth from 1985 (102 percent). Materials engineering (including materials science) was the second-largest subfield ($189 million), and it too had a high growth rate from 1985 to 1988 (120 percent). The other major engineering subfields had smaller amounts of research equipment and lower instrumentation growth rates during this period (56-76 percent).

- **Types of Equipment**. Computers and related equipment accounted for one-third (33 percent) of the total instrumentation investment in engineering; they constituted nearly half of the equipment investment in electrical engineering (49 percent).

- **Perceptions**. More often than not, heads of engineering departments reported improvements over the last three years in the amount (69 percent of departments) and overall adequacy (51 percent) of their research equipment. On the other hand, 80 percent reported that their instrumentation needs have increased over the last three years, and 70 percent still reported that there are important research areas where investigators in their department are unable to perform critical experiments due to lack of needed equipment.

- **Sources of Funds**. Federal funding support accounted for 38 percent of the total 1988 investment in engineering research equipment, down somewhat from 45 percent in 1982; on the other hand, the share contributed by state government appropriations increased from 5 percent in 1982 to 15 percent in 1988. Most other funding sources maintained stable funding shares over this period.

- **Federal Focus**. Federal funding support increased most rapidly for relatively high-cost equipment. For engineering research equipment in the $400,000 to $999,999 range, the Federal funding share grew from 29 percent in 1985 to 50 percent in 1988.

- **Needs**. The perceived need for Federal instrumentation support among engineering department heads exhibited a similar shift. In 1986, only 24 percent recommended equipment costing $50,000 or more as the principal area needing increased Federal support; by 1989, this figure had increased to 58 percent.

Background and Statement of Limitations

The data in this report come from the *National Survey of Academic Research Instruments and Instrumentation Needs*. This triennial survey program is conducted by the National Science Foundation (NSF), with major support from the National Institutes of Health (NIH). It is designed to monitor emerging instrumentation needs and trends in the amounts, costs, and characteristics of academic research equipment in selected science/engineering (S/E) fields. The survey program was undertaken in response to a Congressional directive to the Foundation to "develop indices, correlates or other suitable measures or indicators of the status of scientific instrumentation in the United States and of the current and projected need for scientific and technological instrumentation."[1]

The most recent data were collected in 1989 from a sample of engineering departments and research centers and from all computer science departments and academic computer centers at a sample of 55 universities and colleges statistically selected to represent the 174 largest R&D-performing institutions in the nation. The sampled institutions are listed in Appendix A. The universe this sample represents consists of those universities and colleges with reported nonmedical S/E R&D expenditures of $3 million or more in Fiscal Year 1984, which collectively represented 90 percent of all FY 1984 nonmedical academic S/E R&D expenditures.[2]

The 55 sampled institutions contained a total of 396 eligible engineering departments and research centers in 1989, from which a stratified probability sample of 281 was selected. These institutions also contained 56 eligible computer science departments and facilities and 62 computer centers, all of which were included. The heads of these departments and centers were asked to complete a department questionnaire concerning their expenditures, priorities, and needs for research equipment. Computer center administrators were also asked to complete a brief questionnaire about the age, type, and dollar amount of equipment in their centers.

In addition, samples of existing research equipment were selected in each surveyed engineering and computer science department and research center, and the responsible principal investigator was asked to complete a brief data form concerning each instrument's cost, age, condition, etc. The equipment sample was selected to represent all instrument systems originally costing $10,000 or more that were used for S/E research at any time in 1988. The resulting data were statistically weighted to represent all such equipment at all institutions represented in the survey. All of the data shown in this report are in the form of national estimates developed from these samples. As estimates, they are subject to variability due to sampling error. Estimates of the sampling errors associated with the survey statistics, and additional information about details of the study's sample design and data collection instruments and procedures, are available upon request from NSF. Detailed statistical tables, from which the information presented in this report was distilled, are also available upon request.[3]

All 55 sampled institutions participated in the 1989 survey, and data were obtained from all of the 62 computer centers at these institutions. Usable questionnaire responses were obtained from heads of 302 of the 337 surveyed engineering and computer science departments and research centers (90 percent) and about 3,408 of the 3,954 sampled research instruments in these departments/centers (86 percent).

Findings from the current (1989) survey are compared to those from similar surveys conducted in 1986 and 1983 to examine trends over the three-year intervals between surveys.[4] In all three surveys, information about current equipment needs and priorities was obtained with reference to the year the survey was conducted; information about equipment amounts and expenditures refers to the year prior to the survey (i.e., 1988, 1985, and 1982, respectively).

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[1] An Act To Authorize Appropriations for Activities for the National Science Foundation for Fiscal Year 1980, and for Other Purposes. Public Law 96-44, Section 7.

[2] Academic Science/ Engineering: R&D Funds, Fiscal Year 1984, Detailed Statistical Tables, NSF, 1985.

[3] For further information, contact Dr. Eileen Collins at NSF/SRS, (202) 634-4655.

[4] For a detailed presentation of findings from these earlier studies, see: National Science Foundation, Academic Research Equipment in Selected Science/Engineering Fields: 1982-83 to 1985-86, SRS 88-D1, June 1988.

In each of the three subject areas examined (computer science, academic computer centers, and engineering), this report first describes current status and recent trends in existing and needed research equipment. For engineering and computer science, it then presents statistical profiles contrasting the 20 largest (and, presumably, best-equipped) R&D-performing institutions in the field to institutions with smaller research programs in that field on various indices of the average current amount, composition, and adequacy of their research equipment. These profiles are intended to: (a) describe the kinds and amounts of equipment that are to be found at the best-equipped academic research programs in the nation, and (b) assess how the equipment situations of the institutions with smaller research programs compare to those of the best-equipped institutions.

Throughout this report, there are many references to percent change in equipment dollar amounts from 1985 to 1988. All such "percent change" figures are adjusted for inflation, based on U.S. Bureau of Labor Statistics Producer Price Indices for equipment-related products.

Computer Science

The 174 institutions represented in this survey contained an estimated 147 computer science departments and facilities with at least one research instrument system costing $10,000 or more. This does not include academic computer centers, which are discussed separately.

Annual Expenditures

Substantial growth occurred in college/university computer science departments from 1982 to 1985. During that period, many new departments were created, total R&D expenditures grew from $148 million to $281 million,[5] and annual purchases of research equipment more than doubled, from $20 million in 1982 to $49 million in 1985 (Table 1).[6] From 1985 to 1988, the number of computer science departments and facilities remained stable, the rate of growth in overall R&D spending slowed,[7] and research equipment purchases declined slightly, to $45 million in 1988. This levelling off of equipment purchases may reflect a general stabilization in the size of the field, decreasing unit costs of much computing equipment, increasing reliance on large supercomputer centers for much computer science research (central computer centers are discussed later in this report, and are not included here), and other factors.

Total expenditures for maintenance and repair of computer science research equipment, after more than doubling from $6 million in 1982 to $16 million in 1985, remained relatively stable at $17 million in 1988. Nevertheless, a shift appeared in the relative proportions of expenditures devoted to outside maintenance (service contracts and field service) as compared to maintenance by institution personnel -- the two categories were about equal in 1985, but by 1988 expenditures for service contracts and field service grew to account for about 70 percent of all maintenance and repair expenditures.

Table 1. Trends in equipment-related annual expenditures in computer science departments, 1982-88

Type of expenditure	1982	1985	1988
	(millions)		
Equipment purchases	$20	$49	$45
Maintenance and repair	6	16	17
Service contracts & field services	-	8	12
Other (salaries, tools, etc.)	-	7	5
Operation of research equipment	-	-	15
Technician salaries	-	-	12
Other (e.g., supplies)	-	-	3

Note: Details may not add to totals because of rounding.

SOURCE: National Science Foundation, SRS

Expenditures for the operation of computer science research equipment were ascertained for the first time in the 1989 survey. These costs, which totaled $15 million, include an estimated $12 million for technician salaries and $3 million for supplies, power, and other operating expenses. When combined with the $17 million in annual maintenance/repair costs, the annual cost of maintaining existing research equipment in computer science is almost as great as the annual expenditures for purchase of new research equipment: $32 million versus $45 million.

Inventory Size and Composition

The aggregate purchase price of all in-use computer science research equipment in the $10,000 and above range more than doubled from 1982 ($50 million) to 1985 ($114 million), as did annual equipment purchases. However, in contrast to the flattening-out that occurred in annual purchases from 1985 to 1988, the accumulated national stock of computer science research equipment continued to grow over this period, though at a reduced pace. By the end of 1988, there was $168 million in such equipment, an inflation-adjusted increase of 43 percent since 1985 (Table 2).

[5] National Science Foundation, Academic Science/Engineering R&D Funds: Fiscal Year 1988, NSF 89-326, Washington, DC, 1990, p. 17.

[6] All statistics concerning *annual* equipment-related expenditures refer to expenditures for purchase or operation of nonexpendable research equipment costing $500 or more per unit.

[7] NSF 89-326, p. 17.

Table 2. Aggregate purchase price of academic research equipment costing $10,000 or more per system in computer science departments, by cost range, location and type, 1985-88

Equipment location price, and type	1985	1988
	(millions)	
Total	$114	$168
Department	101	127
Nondepartmental research center	12	34
Other	1	7
	(percent of total price)	
Price range		
$10,000-49,999	35	38
$50,000-99,999	16	24
$100,000-399,999	32	27
$400,000-999,999	13	9
$1 million or more	5	2
Type of equipment		
Computer system costing $200K+	25	21
(Mini) computer system costing $50-$199K, and peripherals	39	39
Single-user workstations ($10-$49K) and networks	27	35
Graphics/CAD/imaging equipment	5	3
Other	4	2

Note: Details may not add to totals because of rounding.

SOURCE: National Science Foundation, SRS

Most of this equipment was located in traditional academic departments ($127 million, or 76 percent), although a significant -- and growing -- amount ($34 million, or 20 percent) was found in specialized nondepartmental research centers.

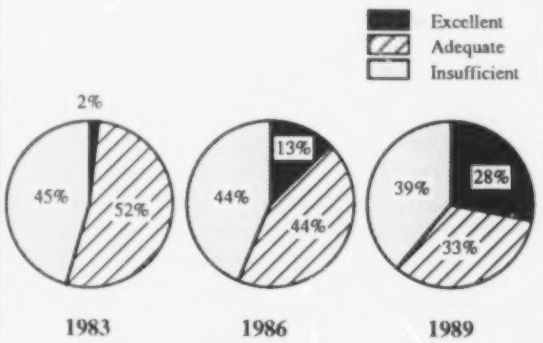
In 1985, 51 percent of the total investment represented by all in-use computer science research equipment was concentrated in equipment systems costing less than $100,000 (Table 2). By 1988, this percentage had risen to 62 percent. To some slight extent, this trend may reflect price reductions for computing equipment. It also indicates a growing prominence in computer science departments of personal computers and other computing equipment at the low end of the survey price range.[8] Single-user workstations and networks, which accounted for 27 percent of the investment represented by the 1985 stock of in-use computer science research equipment, grew to 35 percent of the 1988 stock.

[8] Because this analysis is based on defining specific price ranges, no inflation adjustments were used in calculating these estimates.

Department Assessments

The heads of many computer science departments/facilities reported recent qualitative improvements in their research equipment and support services. When asked to assess the capability of existing equipment to enable faculty investigators to pursue their major research interests, 28 percent of department heads in 1989 described their capability as *excellent*, compared with 13 percent in 1986 and only 2 percent in 1983 (Figure 1). However, 39 percent still viewed their equipment as *insufficient*, a relatively modest change from the 45 percent in 1983.

Figure 1. Computer science department heads' assessments of the capability of existing equipment to enable faculty investigators to pursue their major research interests: 1983, 1986 and 1989



NOTE: Percentages may not sum to 100 because of rounding.
Source: National Science Foundation, SRS

Besides providing an overall evaluation of the equipment in their departments, department heads were asked specifically to describe changes from 1986 to 1989 in the amount and adequacy of their research equipment. Three-fourths of the computer science department heads reported either a *substantial increase* (i.e., more than a 50-percent increase in aggregate cost) in their amount of research equipment over this three-year period (31 percent of departments) or an increase of 10-49 percent in aggregate cost (44 percent; Table 3). Improvements in the general adequacy of their research equipment were also reported by 58 percent of computer science department heads, while declines were reported by only 14 percent.

Table 3. Computer science department heads' assessments of recent changes in equipment amount and adequacy, 1989

Department heads' assessment	Percent of departments
Total	100
Change in amount of usable research equipment in last 3 years	
Increased substantially (more than 50%)	31
Increased	44
Remained the same (within 10%)	17
Decreased	7
Decreased substantially (more than 50%)	0
Change in adequacy of research equipment in last 3 years	
Improved	58
Remained the same	28
Declined	14

Note: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, SRS

Sources of Inventory Funding

Over the period 1982 to 1988, sources of equipment funding support for computer science departments have remained fairly stable (Table 4). In 1988, Federal funding accounted for slightly less than half of the aggregate dollar amount of all in-use research equipment in the $10,000 to $1 million range (42 percent), with the Department of Defense (22 percent of the total) and NSF (17 percent) being the principal Federal funding agencies. Non-Federal equipment funding support has come primarily from private/industry sources (29 percent in 1988) and from internal institution funds (24 percent).

Recent Federal funding has been most important for systems costing $400,000 to $999,999, where the percentage of investment supplied by the Federal government increased from 23 percent in 1985 to 58 percent in 1988 (Table 4). The Federal share for all other cost ranges declined.

While the general trend was for the aggregate amount of both Federal and non-Federal funding to increase from 1985 to 1988, reported increases were not evenly distributed across departments. Thus, only 35 percent of computer science department heads' reported an increase in Federal equipment funding, and 33 percent reported an increase from industry (Figure 2).

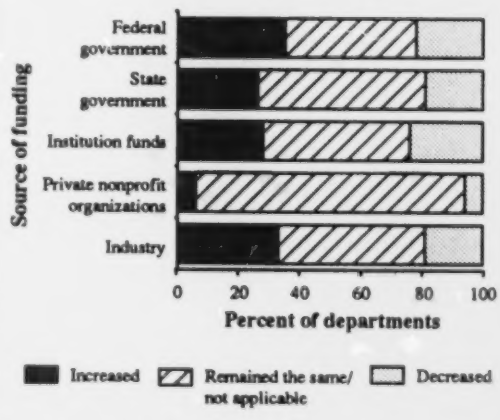
Table 4. Sources of funds for acquisition of computer science research equipment, 1982-88

Source of funds	1982	1985	1988
Total (millions of dollars)	$50	$109	$164
		(percent)	
Federal sources	44	53	42
NSF	22	29	17
NIH	1	1	1
Department of Defense	19	20	22
Department of Energy	1	1	1
Other	2	2	1
Non-Federal sources	56	47	58
Institution funds	23	21	24
State government	10	3	3
Private/industry	23	22	29
Other	1	1	2
Federal percent of total funding			
$10,000-49,999	-	61	48
$50,000-99,999	-	72	41
$100,000-399,999	-	46	29
$400,000-999,999	-	23	58

Note: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, SRS

Figure 2. Changes in instrumentation funding support over the last three years in computer science, by source of funding: 1989



Source: National Science Foundation, SRS

Equipment Needs and Priorities

In 1989, the great majority of computer science department heads' (85 percent) reported that the instrumentation needs of their research programs have increased over the last three years because of expanding staff, growing research programs, or other factors. No department heads said their instrumentation needs have declined.

Despite departments' generally increasing equipment needs, there is some evidence to suggest that the gap between needed and available equipment may be narrowing at some computer science departments. In 1983, 93 percent of all computer science department heads reported that their researchers could not perform critical experiments in their areas of greatest interest due to the lack of needed equipment. By 1989, that number had declined markedly, to 59 percent, though it still represented a majority of departments.

It was noted earlier that, although the greatest recent increases in investment have been for equipment at the low end of the study cost range (i.e., equipment in the $10,000 to $99,999 range), Federal support has become increasingly focused on relatively "big ticket" equipment. Apparently, this focus is congruent with department needs. In 1989, over half of the computer science department heads (58 percent) said that increased Federal funding for equipment would be most beneficial for equipment in the $50,000 and above range, a marked increase over the 24 percent reporting this opinion in 1986 and the 26 percent in 1983 (Table 5).

Table 5. Department heads' assessments of where increased Federal funding would be most beneficial in computer science, by cost range, 1983-89

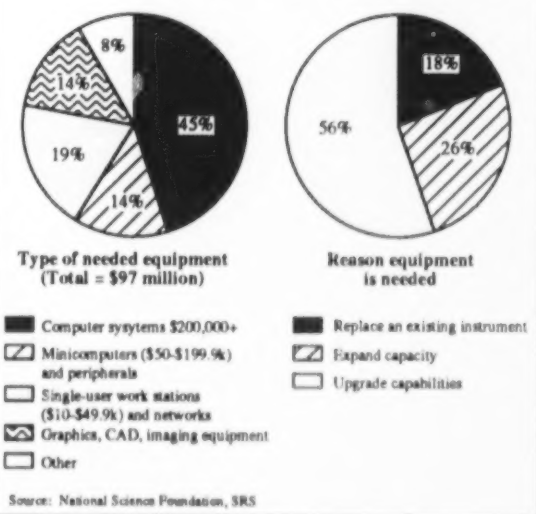
Cost range	1983	1986	1989
		(percent)	
Systems over $1 million	-	0	7
Systems in $50,000-$1 million range	26	24	51
Systems in $10,000-$50,000 range	74	66	41
Enhancement of general lab equipment (generally less than $10,000)	0	3	0
Other systems	0	6	1

Note: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, SRS

To better identify department needs, each department head was asked to describe and estimate the cost of the three top-priority research instrument needs of his or her department. Aggregating all of the responses, large computer systems costing $200,000 or more accounted for nearly half (45 percent) of the aggregate dollar amount of this most-needed equipment (Figure 3). At the other end of the price spectrum, single-user workstations ($10,000 to $49,999) and networks accounted for the second largest share of the total (19 percent).[9]

Figure 3. Equipment listed among top three priorities for acquisition in computer science: 1989



Source: National Science Foundation, SRS

Most of the desired equipment (56 percent of aggregate price), was needed to upgrade departmental capabilities (i.e., to perform experiments that could not be done with existing equipment). Other equipment was needed to expand current capacity by providing more copies of already existing equipment (26 percent), or to replace an existing instrument (18 percent).

Institution Profiles

This section contrasts the 20 largest computer science research programs, in terms of 1988 R&D expenditures, to institutions with smaller research programs in this field on measures of average program size and composition. The heads of the 20 largest computer science programs reported mean R&D expenditures of $14 million per institution in

[9] Institutions often indicate needs for multiple copies of such equipment (e.g., $125,000 for 5 workstations at $25,000 each).

this field in 1988, and these institutions collectively accounted for 69 percent of all computer science R&D expenditures.[10]

As would be expected, the largest R&D performers have higher average annual expenditures for purchase of computer science research equipment than do institutions with smaller computer science research programs ($785,000 versus $259,000; Table 6), as well

Table 6. Program characteristics, annual expenditures and perceptions in computer science, by size of research program, 1988-89

Statistic	Institution R&D rank in computer science*	
	20 largest	Other
AVERAGE PROGRAM CHARACTERISTICS		
Mean no. full-time faculty researchers	23.3	11.8
Mean no. Ph.D.s awarded last year	8.2	2.4
MEAN ANNUAL EXPENDITURES PER INSTITUTION		
Research equipment purchases	$785,000	$259,000
Maintenance/repair of research equip	273,000	98,000
Service contracts & field service	195,000	71,000
Other (salaries, tools, etc.)	78,000	27,000
Operation of research equipment	282,000	84,000
Technician salaries	205,000	68,000
Other (e.g., supplies)	77,000	15,000
PERCEPTIONS	(percent of departments)	
Current amount of research equipment is insufficient	0%	44%
Department's research equipment has increased substantially (50%+) in past 3 years	48	29
The adequacy of the department's research equipment has improved in past 3 years	60	58
Federal equipment support has decreased in past 3 years	46	19

*Based on institutions' FY1988 R&D expenditures in computer science.

SOURCE: National Science Foundation, SRS

as a much larger average dollar amount of in-use research equipment ($4,895,000 versus $735,000; Table 7). In addition to these expected absolute differences in program size, many other differences between the two institution categories were found.

[10] NSF 89-326, p. 125.

On average, at the 20 largest computer science institutions:

- A much larger proportion of the current research equipment investment was located outside traditional academic departments, in specialized nondepartmental research centers (43 percent versus 3 percent; Table 7);

Table 7. Characteristics of computer science research equipment by size of research program, 1988

Characteristic	Institution R&D rank in computer science*	
	20 largest	Other
Mean dollar amount of computer science research equipment per institution	$4,895,000	$735,000
Location (percent of total)		
Department	57%	97 %
Nondepartmental research center	43	3
System price range (percent of total)		
$10,000-$49,000	41	35
$50,000-$99,999	31	19
$100,000-$399,999	14	36
$400,000-$999,999	9	9
$1 million or more	6	0
OTHER INDICES		
Mean $ amount of research equipment per full-time faculty researcher	$198,000	$62,000
Mean $ amount of research equipment per doctoral degree awarded last year	$567,000	$309,000
Mean number of research users per system in 1988	34.6	30.3
1988 maintenance/repair expenditures per $1,000 of research equipment	$41.04	$67.33

*Based on institutions' FY1988 R&D expenditures in computer science.

NOTE: Percentages may not add to 100 because of rounding.

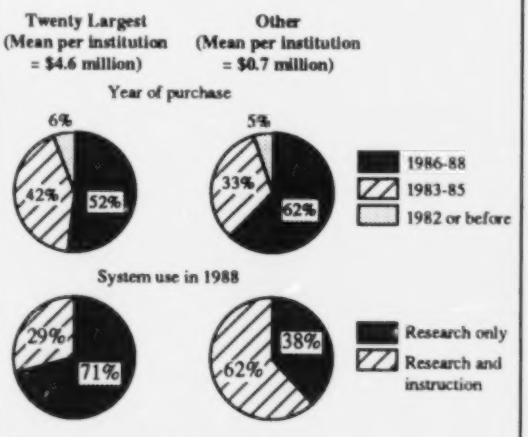
SOURCE: National Science Foundation, SRS

- A larger proportion of the current equipment investment was concentrated in items and systems costing under $100,000 (72 percent versus 54 percent; Table 7);

- A smaller proportion of the current equipment investment was acquired in the last three years (52 percent versus 62 percent; Figure 4);

- A much smaller proportion of the current equipment investment was for equipment used for both research and instruction, as opposed to research only (29 percent versus 62 percent; Figure 4);

Figure 4. Distribution of current investment in computer science research equipment by year of purchase and by equipment use: comparison of the 20 largest computer science research programs to institutions with smaller programs, 1988



Source: National Science Foundation, SRS

- The average amount of equipment per faculty researcher was larger ($198,000 versus $62,000), but so was the average level of research usage per system (35 users per system per year versus 30; Table 7); and

- Average annual maintenance/repair expenditures per $1,000 of in-use research equipment were lower ($41 versus $67; Table 7).

With respect to perceptions, heads of computer science departments at the 20 largest R&D institutions were less likely to say their equipment was *insufficient* (no departments, compared with 44 percent at other institutions; Table 6). Computer science department heads at the largest institutions also gave more favorable evaluations of changes that had occurred over the last three years. For example, they were more likely to say the amount of research equipment had increased more than 50 percent (48 percent, compared with 29 percent). Not all evaluations of change were favorable, however. Department heads at the largest institutions were more likely to report a decrease in Federal equipment support (46 percent) than those at other institutions (19 percent).

Academic Computer Centers

The foregoing analysis of computer science research equipment did not include equipment located in institutions' central mainframe computer facilities. In 1988, the 174 research-performing institutions represented in this survey contained an estimated 179 such centers, about one per institution. These facilities provide an important equipment resource for research in the field of computer science, and in other fields as well. Trends in the kinds and amounts of equipment in such computer centers are summarized in this section.

The data include information for five large NSF-funded supercomputer centers, which are newer and larger than most other academic computer centers and are discussed separately.

Annual Expenditures

In 1988, academic computer centers purchased a total of $187 million of computing equipment (Table 8). Of this, $19 million was spent at the five NSF supercomputer centers for an average of about $4 million per center. Other academic computer centers purchased $168 million of computing equipment for an average of about $1 million per computer center.

Table 8. Equipment-related annual expenditures in computer centers, 1988

Type of expenditure	Total	NSF supercomputer centers	Other computer centers
	(millions)		
Equipment purchases	$187	$19	$168
Maintenance and repair	84	7	77
Service contracts & field services	62	4	58
Other (salaries, tools, etc.)	22	3	19
Operation of research equipment	250	30	220
Technician salaries	156	12	144
Other (e.g., supplies)	94	18	76

SOURCE: National Science Foundation, SRS

In 1988, an estimated $84 million was spent for maintenance and repair of equipment at academic computer centers. As with computer science equipment, about three-fourths of these expenditures were on service contracts and field service.

Operation of computer center equipment required an additional $250 million in 1988. Thus, unlike computer science, more funds were spent on the operation of existing equipment at computer centers than on the purchase of additional equipment.

Inventory Size and Composition

As also happened for computer science research equipment, the aggregate dollar amount of in-use research equipment at academic computer centers more than doubled from 1982 ($423 million) to 1985 ($877 million) and then grew at a lower rate from 1985 to 1988, increasing by an inflation-adjusted 37 percent, to $1.3 billion (Table 9).

Table 9. Aggregate purchase price of academic research equipment costing $10,000 or more per system at computer centers, by type of computer center, 1985-88

Type of computer center	1985	1988
	(millions)	
Total	$877	$1,256
NSF supercomputer centers	16	247
Other computer centers	861	1,009

SOURCE: National Science Foundation, SRS

Much of the overall dollar growth in academic computer centers in 1985-88 was due to an expansion of the NSF supercomputer program, which grew from $16 million of on-line equipment in 1985 to $247 million in 1988. Although several other institutions replaced their existing mainframes with more powerful systems in the supercomputer range during this period, the aggregate dollar amount of equipment in non-NSF academic computer centers grew only slightly, from $861 million in 1985 to $1.006 billion, an increase of 13 percent after adjustment for inflation. Thus, it appears that, while there has been rapid growth both in very large computer centers (those in the supercomputer range) and in decentralized computing equipment (department-based personal computers and minis), midrange central computer centers are playing an increasingly ambivalent role in academic research.

Assessments

The heads of three (60 percent) of the NSF supercomputer centers described their equipment capabilities as excellent, and none said their equipment was insufficient for research (Table 10). In contrast, only 17 percent of the directors at other academic computer centers reported excellent equipment capabilities, and 31 percent described their equipment as insufficient to meet their research needs.

Table 10. Computer center directors' assessments of their equipment and support services, 1989

Assessment	Total	NSF supercomputer centers	Other computer centers
			(percent)
Total	100	100	100
Capability to pursue major research interests			
Excellent	18	60	17
Adequate	52	40	52
Insufficient	30	0	31
Change in amount of usable research equipment in last 3 years			
Increased substantially (more than 50%)	25	80	23
Increased	36	0	37
Remained the same (within 10%)	30	20	31
Decreased	8	0	9
Decreased substantially (more than 50%)	0	0	0
Change in adequacy of research equipment in last 3 years			
Improved	49	80	48
Remained the same	36	20	36
Declined	15	0	16

Note: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, SRS

Computer center directors were asked to describe how the amount and adequacy of their research equipment had changed in the last three years. Consistent with the inventory trend data reported earlier, four (80 percent) of the NSF computer center directors reported substantial increases in their amount of usable research equipment, i.e., increases of more than 50 percent in aggregate value in the last three years (Table 10). Substantial increases were also reported by 23 percent of the directors of other computer centers; an additional 37 percent of other computer center directors reported equipment increases in the 10-50 percent range. Improvements in the overall adequacy of their equipment were reported by four (80 percent) of the NSF supercomputer center directors and by half (48 percent) of other computer center directors. No NSF supercomputer center directors and only one-sixth of other computer center directors (16 percent) reported a decline in the adequacy of their research equipment.

Equipment Needs and Priorities

Almost two-thirds (64 percent) of computer center directors reported that researchers were unable to perform critical experiments due to a lack of needed equipment (Table 11).

Like departments of computer science, computer centers also generally experienced increased instrumentation needs over the last three years: this was true for all five NSF supercomputer centers and for three-fourths of other supercomputer and computer centers. All of the NSF supercomputer center directors indicated that increased Federal funding would be most beneficial when applied to systems over $1 million, as did 52 percent of other computer center directors.

Table 11. Computer center directors' assessments of equipment needs and priorities, 1989

Assessment	Total	NSF super-computer centers	Other computer centers
	(percent)		
Cannot do critical experiments due to lack of needed equipment	64	60	64
Changes in instrumentation needs over 1986-89			
Increased	76	100	75
Remained the same	20	0	21
Decreased	4	0	4
Area where increased funding would be most beneficial			
Systems over $1 million	54	100	52
Systems in $50,000-$1 million range	30	0	31
Systems in $10,000-$50,000 range	13	0	13
Enhancement of general lab equipment (generally less than $10,000)	2	0	2
Other systems	1	0	2

SOURCE: National Science Foundation, SRS

Engineering

In 1988, the 174 institutions represented in this survey contained an estimated 942 engineering departments and research facilities with at least one item of research equipment costing $10,000 or more. In addition, they contained an estimated 16 engineering "supersystems" -- large, self-contained research systems outside the department structure, often with large amounts of nonmovable equipment, and usually costing several million dollars (e.g., very large wind tunnels, acoustic test facilities, towing tanks, magnet labs).

Annual Expenditures

After increasing by $78 million from 1982 ($96 million) to 1985 ($174 million), annual purchases of engineering research equipment increased an additional $77 million in 1988 to a total of $251 million, an inflation-adjusted increase of 33 percent (Table 12).[11] Thus, engineering was unlike computer science in that it maintained a steady, nearly linear growth in equipment expenditures over the entire 1982-88 period. This is consistent with trends in the overall level of engineering R&D expenditures, which had a similar rate of growth, from $1.4 billion in 1985 to $2.1 billion in 1988.[12] In both years, instrumentation purchases accounted for about 12 percent of total R&D expenditures in engineering.

Among the major subfields of engineering, electrical engineering purchased the largest amount of research equipment in 1988 ($61 million), accounting for 24 percent of the engineering total. However, equipment expenditures grew at faster rates from 1985 to 1988 for materials engineering[13] (up an inflation-adjusted 41 percent to $41 million) and mechanical engineering (up 31 percent to $32 million) than for electrical engineering (up 19 percent). Expenditures in chemical and civil engineering remained relatively stable.

Table 12. Trends in equipment-related annual expenditures in engineering, 1982-88

Type of expenditure	1982	1985	1988
	(millions)		
Equipment purchases, total	$96	$174	$251
Electrical	31	47	61
Mechanical	8	23	32
Materials	17	27	41
Chemical	10	17	17
Civil	11	12	14
Other	19	49	85
Supersystems	-	-	3
Maintenance and repair	21	33	38
Service contracts & field services	-	13	15
Other (salaries, tools, etc.)	-	20	23
Operation of research equipment	-	-	88
Technician salaries	-	-	73
Other (e.g., supplies)	-	-	15

Note: Details may not add to totals because of rounding.

SOURCE: National Science Foundation, SRS

Expenditures for maintenance and repair of research equipment increased modestly from $33 million in 1985 to $38 million in 1988, following a much larger increase from $21 million in 1982 (Table 12). Unlike computer science and computer centers, engineering departments spent less on outside maintenance/repair (service contracts and field service) than on institution-provided maintenance/repair ($15 million versus $23 million) in 1988. A total of $88 million was spent on the operation of research equipment in engineering in 1988, of which $73 million (83 percent) was devoted to technician salaries.

Inventory Size and Composition

From 1982 to 1985, the aggregate purchase price of all in-use engineering research equipment in the $10,000 to $1 million range increased from $295 million to $435 million. Over the following three years, from 1985 to 1988, the amount of equipment in this cost range grew at an even faster pace, nearly

[11] This does not include the 16 engineering supersystems, which purchased an additional $3 million in research equipment in 1988. Information is not available about previous spending levels at these installations.

[12] NSF 89-326, p. 17.

[13] As used here, "materials engineering" includes materials science research facilities, departments of materials science and engineering, and departments of ceramic, materials, metallurgical, mining, and petroleum engineering.

doubling to $828 million, an inflation-adjusted increase of 86 percent (Table 13). This is about twice the rate of growth that was seen for instrumentation in computer science (43 percent) and computer centers (37 percent) over this same period.

Table 13. Aggregate purchase price of academic research equipment costing $10,000 or more per system in engineering, by subfield, location, and price range 1985-88

Engineering equipment subfield, location, and price	1985	1988
	(millions)	
Total, except supersystems	$462	$884
Systems costing $10,000-$999,999	435	828
Systems costing $1 million or more	27	56
Engineering subfield		
Electrical	120	249
Mechanical	80	129
Materials	84	189
Chemical	38	66
Civil	32	57
Other	109	194
Location		
Department	359	702
Nondepartmental research center	103	182
	(percent of investment)	
Price range		
$10,000-49,999	37	37
$50,000-99,999	19	17
$100,000-399,999	27	28
$400,000-999,999	11	11
$1 million or more	6	6

Note: Details may not add to totals because of rounding.

SOURCE: National Science Foundation, SRS

As well as the $828 million in 1988 research equipment costing under $1 million per unit, engineering departments and research facilities contained $56 million in research systems with unit costs of $1 million or more, and engineering supersystems contained an additional $49 million in movable research equipment, for a total approaching $1 billion ($932 million).

Among the subfields of engineering, the greatest dollar amount of research equipment was in electrical engineering ($249 million), which also had one of the highest rates of growth from 1985 to 1988 (102 percent).[14] Materials engineering had the single highest growth rate (120 percent) and the second-largest total amount of research equipment ($189 million). The remaining major subfields of engineering had rates of growth in research instrumentation that were substantial (56-76 percent), but well below those of the two largest subfields (Table 13).

Over one-third of the total investment in engineering research equipment was concentrated on equipment in the $10,000 to $49,999 price range (37 percent in both 1988 and 1985). The equipment price distribution did not change significantly from 1985 to 1988, with each price range maintaining essentially equivalent proportions for both time periods (Table 13).

In contrast to computer science departments and computer centers, where existing research instrumentation consisted almost entirely of computers, a wide variety of equipment types were found in engineering. The largest single category was computers and data handling equipment, accounting for 33 percent of the $829 million in equipment in the $10,000 to $999,999 range (Table 14). Other categories accounting for relatively large amounts of equipment were materials testing equipment (11 percent) and "major prototype instrument systems" (12 percent; $99 million). The latter category includes custom built systems costing over $100,000, such as wind and water tunnels ($24 million) and other high-cost instruments such as laser-doppler velocimeters ($26 million), electron/ion/molecular beam systems ($38 million), and sputtering/deposition/plasma etch systems ($11 million).

The types of in-use research equipment varied considerably among the subfields of engineering. For electrical engineering (which includes computer engineering), the major category was computers and data handling equipment (49 percent), with another 21 percent ($50 million) in major prototype instrument systems such as molecular beam epitaxy and other electron/ion/molecular beam systems ($13 million). Materials engineering, on the other hand, had relatively small investments in computers (10 percent) and major prototype instrument systems (11 percent), but had substantial investments in

[14] These growth rate figures have been adjusted for inflation.

Table 14. Types of engineering research equipment costing $10,000 to $1 million, by subfield, 1988

Equipment type	Total	Engineering subfield					
		Electrical	Mechanical	Materials	Chemical	Civil	Other
				(millions of dollars)			
Total	$828.7	$236.5	$126.8	$186.8	$65.5	$50.0	$163.1
				(percent of investment)			
Computers and data handling	33	49	42	10	28	27	33
Computer systems $200K+	7	8	17	2	9	-	6
Minicomputers ($50-199K) & peripherals	10	16	10	3	4	7	13
Workstations ($10-49K) & networks	9	15	6	3	9	9	10
All other computer systems	7	10	9	2	6	11	5
Materials testing	11	2	13	18	1	29	14
Microscopes & accessories	6	1	<1	22	1	1	4
Recorders, cameras, & elec. apparatus	7	8	10	5	3	3	7
Spectroscopy & light measurement	7	4	2	16	19	4	1
Major prototype instrument systems	12	21	8	11	11	6	5
All other equipment	24	15	24	18	36	29	35

NOTE: Percentages may not add to 100 because of rounding.

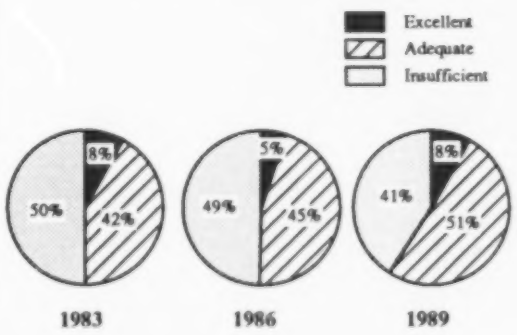
SOURCE: National Science Foundation, SRS

microscopes and accessories (22 percent), materials testing equipment (18 percent), and spectroscopy and light measurement equipment (16 percent). Equipment investments in mechanical and civil engineering were both heavily concentrated in computing and materials testing equipment (which together accounted for over 55 percent of total investment in both subfields).

Department Assessments

Engineering department heads tended to report recent improvements in the adequacy of their research equipment, though not to the same degree as was seen in computer science. The percentage describing their equipment as *insufficient* declined moderately from 50 percent in 1983 to 41 percent in 1989 (Figure 5).

Figure 5. Capability of existing equipment to enable engineering faculty investigators to pursue their major research interests: 1983, 1986 and 1989



NOTE: Percentages may not sum to 100 because of rounding.
Source: National Science Foundation, SRS

Most department heads (69 percent) reported increases in their amount of research equipment over the last three years: 23 percent saw a substantial increase, and 46 percent a moderate increase (Table 15). In addition, half of the engineering department heads (51 percent) reported an improvement in the overall adequacy of their research equipment.

Table 15. Engineering department heads' assessments of recent changes in equipment amount and adequacy, 1989

Departmental assessment	Percent of departments
Total	100
Change in amount of usable research equipment in last 3 years	
Increased substantially (more than 50%)	23
Increased	46
Remained the same (within 10%)	27
Decreased	4
Decreased substantially (more than 50%)	0
Change in adequacy of research equipment in last 3 years	
Improved	51
Remained the same	33
Declined	16

Note: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, SRS

Consistent with the longitudinal data on trends in inventory size, reports of substantial increases in amounts of research equipment (i.e., increases of over 50 percent in aggregate dollar value) were especially widespread among electrical engineering departments (49 percent), and electrical engineering department heads were also especially likely to report improvements in the overall adequacy of their research equipment in the last three years (Table 16).

Table 16. Engineering department heads' assessments of their research equipment and equipment trends by subfield, 1983-89

Departmental assessment	1983	1986	1989
	(percent of departments)		
Existing equipment has insufficient capability to enable investigators to pursue major research interests			
Electrical	58	58	43
Mechanical	54	68	39
Materials	50	29	21
Chemical	49	43	39
Civil	44	60	45
Other	48	45	50
Substantial increase (more than 50%) in amount of usable research equipment in last 3 years			
Electrical	-	-	49
Mechanical	-	-	21
Materials	-	-	14
Chemical	-	-	27
Civil	-	-	10
Other	-	-	18
Adequacy of research equipment has improved in last 3 years			
Electrical	-	-	64
Mechanical	-	-	48
Materials	-	-	35
Chemical	-	-	45
Civil	-	-	52
Other	-	-	57

SOURCE: National Science Foundation, SRS

Sources of Inventory Funding

In relative terms, funding support for engineering research equipment has remained fairly stable over the period 1982-88. Overall Federal funding support declined somewhat, from 48 percent of the total in 1982 to 38 percent in 1988, but this was offset by a relative increase in support from state government appropriations, which rose from 6 percent in 1982 to 15 percent in 1988 (Table 17). Most other engineering equipment funding sources showed little fluctuation in their relative share of the total funding pie.

In the 1985-88 period, Federal funding support for engineering research equipment became increasingly focused on "big ticket" items costing $400,000 or more. Federal funding accounted for only 29 percent

of the total investment in such items in 1985, but it grew to 50 percent in 1988 (Table 17). The opposite trend was seen for equipment at the other end of the cost range. Thus, Federal funding accounted for 40 percent of the total investment in $10,000 - $49,999 items in 1985, but declined to 31 percent by 1985.

Table 17. Sources of funds for acquisition of research equipment in engineering, 1982-88

Source of funds	1982	1985	1988
Total (millions of dollars)	$295	$435	$829
		(percent)	
Federal sources	48	42	38
NSF	17	14	13
NIH	1	1	1
Department of Defense	19	15	17
Department of Energy	6	6	4
Other	5	5	3
Non-Federal sources	52	58	62
Institution funds	30	28	27
State government	6	8	15
Private/industry	14	20	19
Other	2	2	2
System purchase price (Federal percent of total funding)			
$10,000-49,999	-	40	31
$50,000-99,999	-	42	41
$100,000-399,999	-	49	40
$400,000-999,999	-	29	50

Note: Details may not add to totals because of rounding.

SOURCE: National Science Foundation, SRS

Increases in equipment inventories were especially pronounced at public institutions, which increased from $302 million in 1985 to $592 million in 1988 (an inflation-adjusted 91 percent increase; Table 18). Private institutions had a lower inventory growth rate (74 percent), and the inventory dollar increase was only about one-third as great as that at private institutions. The result is that public institutions, which contained 69 percent of the 1985 national inventory of engineering research equipment, contained an even larger share in 1988 (71 percent). This is consistent with a similar shift seen in overall engineering R&D expenditures, where the public institution share grew from 60 percent in 1985 to 64 percent in 1988.[15]

Table 18. Sources of funds for acquisition of research equipment in engineering by institutional control, 1985-88

Source of funds	Private		Public	
	1985	1988	1985	1988
	(millions)			
Total	$133	$237	$302	$592
Federal, total	79	130	102	183
NSF	36	53	27	54
NIH	1	2	3	7
Department of Defense	29	58	37	80
Department of Energy	3	9	25	26
Other	9	7	10	17
Non-Federal, total	54	107	200	409
Institution funds	24	49	98	172
State government	-	10	-	114
Private/industry	25	46	62	110
Other	4	2	7	13
	(percent)			
Total	100	100	100	100
Federal	60	55	34	31
Non-Federal	40	45	66	69

Note: Details may not add to totals because of rounding.

SOURCE: National Science Foundation, SRS

Public institutions showed a broad mix of equipment funding sources. Federal funding was substantial (at $183 million), but non-Federal funding was considerably greater ($409 million). The greatest amounts were received from institution funds ($172 million), state government ($114 million), private/industry sources ($110 million), and the Department of Defense ($80 million).

Private institutions had a different funding pattern. They received most of their engineering instrumentation funding from Federal sources ($130 million), which increased in total dollars since 1985 but declined in percentage terms (from 60 percent to 55 percent). The largest sources of funding at private institutions were Department of

[15] NSF 89-326, p. 23-26.

Table 19. Engineering department heads' assessments of their equipment needs and priorities, 1983-89

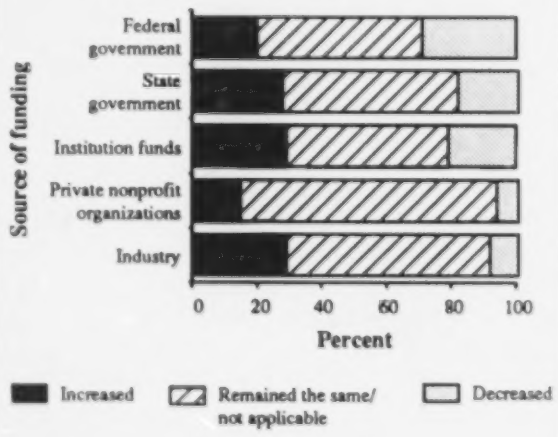
Departmental assessment	Total	Electrical	Mechanical	Materials	Chemical	Civil	Other	Super-systems
				(percent)				
Cannot do critical experiments due to lack of needed equipment								
1983	89	96	92	91	92	90	83	-
1989	70	72	84	71	39	58	75	8
Changes in instrumentation needs over past 3 years								
Increased	80	82	83	75	77	78	82	83
Remained the same	15	5	17	25	23	20	10	17
Decreased	5	13	0	0	0	2	8	0

SOURCE: National Science Foundation, SRS

Defense ($58 million), NSF ($53 million), institution funds ($49 million), and private/industry funds ($46 million).

As with computer science, engineering departments varied greatly in the changes in instrumentation support they experienced. For any given source of funding support (Federal, state, institution, private nonprofit, or industry), at least half of the engineering department heads reported no significant change (Figure 6). Though the value of Federal funding increased 68 percent overall, more department heads reported a decrease in Federal support (29 percent) than an increase (20 percent). State funding more than tripled; nevertheless, increases from this source were reported by only 28 percent of the department heads, and decreases by 19 percent.

Figure 6. Changes in instrumentation funding support over the last three years in engineering, by source of funding: 1989



Source: National Science Foundation, SRS

Equipment Needs and Priorities

Despite the recent influx of equipment, most engineering department heads (70 percent) continue to report that there are important subject areas where their researchers cannot do critical experiments due to a lack of needed equipment, although this proportion is lower than it was in 1983 (89 percent; Table 19). One reason is that reported instrumentation needs have increased between 1986 and 1989 for 80 percent of engineering departments, and decreased for only 5 percent.

The percentage of engineering department heads reporting that increased Federal funding would be most beneficial for systems in the $50,000 and above range increased markedly from 1986 (30 percent) to 1989 (57 percent; Table 20). This is consistent with the observed trends noted earlier toward increased Federal focus on funding of big ticket engineering equipment.

Table 20. Engineering department heads' assessments of where increased Federal funding would be most beneficial, by cost range, 1983-89

Cost range	1983	1986	1989
		(percent)	
Systems over $1 million	-	0	1
Systems in $50,000-$1 million range	28	30	57
Systems in $10,000-$50,000 range	60	58	36
Enhancement of general lab equipment (generally less than $10,000)	9	8	5
Other systems	3	4	0

Note: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, SRS

Table 21. Cost range and reason for top three priorities for acquiring research equipment for engineering, 1989

Characteristics of needed equipment	Total	Electrical	Mechanical	Materials	Chemical	Civil	Other
Total aggregate price (millions of dollars)	$532	$93	$101	$98	$43	$42	$153
Equipment cost range	(Percent of aggregate price of needed equipment)						
$10,000-49,999	3	1	1	1	5	9	3
$50,000-99,999	7	2	12	3	11	8	8
$100,000-399,999	36	32	40	31	36	37	39
$400,000-999,999	40	41	32	42	48	33	43
$1 million or more	14	23	16	22	0	13	8
Reason that equipment is needed							
Replace an existing instrument	13	20	9	18	7	6	12
Expand capacity	30	23	15	30	40	31	42
Upgrade capabilities	57	57	77	51	53	62	47

Note: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, SRS

Another indication of the growing importance of high-cost equipment is that 90 percent of the aggregate cost of the research equipment reported by engineering department heads as being their three top priority needs cost $100,000 or more (Table 21). Much of this equipment was needed to upgrade department capabilities (57 percent of the aggregate price), while 30 percent was needed to expand capacity (more copies of existing equipment), and 13 percent to replace existing instruments.

The overall distribution, by type, of needed research equipment in engineering (Table 22) was generally similar to the distribution of existing research equipment (compare to Table 14), although differences among subfields were perhaps clearer and more pronounced in the equipment needs data. In electrical engineering, for example, high cost molecular beam epitaxy, ion beam lithography, and other electron/ion/molecular beam equipment accounted for nearly a third (32 percent) of the aggregate price of all top priority equipment needs. Materials testing equipment was very prominent among the equipment needs in civil engineering (53 percent of aggregate price) and, to a lesser extent, in mechanical engineering (33 percent). In both materials and chemical engineering, spectroscopy and microscopy equipment together accounted for about 60 percent of the top priority needs.

Institution Profiles

In 1988, the 20 largest engineering R&D performers had mean engineering R&D expenditures of $53 million per institution, and they collectively accounted for half (51 percent) of all academic R&D

Table 22. Types of needed research instruments listed by engineering department heads as their top three priorities by subfield, 1989

Equipment type	Total	Subfield					
		Electrical	Mechanical	Materials	Chemical	Civil	Other
Total (millions of dollars)	$532.2	$92.6	$101	$97.7	$42.5	$41.8	$153.4
		(percent of total)					
Computers and data handling	20	37	25	6	2	9	24
Computer systems $200K+	9	14	19	4	-	-	7
All other computer systems	11	22	6	2	2	9	17
Materials testing	19	2	33	4	4	53	23
Microscopes & accessories	13	8	3	43	24	3	2
Robots, manufacturing machines	6	<1	9	<1	-	1	13
Spectroscopy & light measurement	14	2	9	22	36	11	13
Major prototype instrument systems	16	40	17	10	10	1	12
Electron/ion/molecular beam systems	8	32	3	6	<1	-	3
All others	8	8	14	4	10	1	9
All other equipment	13	11	4	16	24	22	13

Note: Details may not add to totals because of rounding.

SOURCE: National Science Foundation, SRS

expenditures in engineering.[16] This section compares these top 20 engineering research institutions -- which are presumably the best-equipped programs in the nation -- to institutions with smaller engineering research programs on measures of average program size and composition.

The top 20 institutions purchased an average of $4.4 million in engineering research equipment per institution in 1988 (Table 23), and they had accumulated inventories of engineering research equipment averaging $20.6 million per institution (Table 24). On these and other measures of program size, the average for the top 20 institution was four to six times larger than the average for institutions with smaller engineering research programs.

Table 23. Program characteristics, annual expenditures, and perceptions in engineering department, by size of research program, 1988-89

Statistic	Institution R&D rank in engineering*	
	20 largest	Other
AVERAGE PROGRAM CHARACTERISTICS		
Mean no. full-time faculty researchers	191	50
Mean no. Ph.D.s awarded last year	91	17
MEAN ANNUAL EXPENDITURES PER INSTITUTION		
Research equipment purchases	$4,409,000	$1,043,000
Maintenance/repair of research equip	$639,000	$164,000
Service contracts & field service	$281,000	$61,000
Other (salaries, tools, etc.)	$358,000	$102,000
Operation of research equipment	$1,256,000	$405,000
Technician salaries	$961,000	$349,000
Other (e.g., supplies)	$295,000	$56,000
PERCEPTIONS	(percent of departments)	
Current amount of research equipment is adequate or excellent	73	54
Departments' research equipment has increased in past 3 years	81	65
The adequacy of the department's research equipment has improved in past 3 years	61	48
Federal equipment support has decreased in past 3 years	27	29

*Based on institutions' FY1988 R&D expenditures in engineering.

SOURCE: National Science Foundation, SRS

Table 24. Characteristics of engineering research equipment, by size of research program, 1988

Characteristic	Institution R&D rank in engineering*	
	20 largest	Other
MEAN PER INSTITUTION OF SYSTEMS COSTING $10,000 OR MORE		
Aggregate purchase price (millions)	$20,615	$3,278
	(percent of price)	
Location		
Department	77	74
Nondepartmental research center	18	21
Supersystems	5	5
System price range (percent of total)		
$10,000-$49,999	31	39
$50,000-$99,999	18	15
$100,000-$399,999	27	26
$400,000-$999,999	12	9
$1 million or more	11	11
System year of purchase		
1986-88	46	45
1983-85	30	31
1982 or before	24	25
System use in 1988		
Research only	51	45
Research and instruction	49	55
OTHER INDICES		
Mean $ amount of research equipment per FT faculty researcher	$96,000	$58,000
Mean $ amount of research equipment per doctoral degree awarded last year	$202,000	$175,000
Mean number of research users per system in 1988	19.2	17.7
1988 maintenance/repair expenditures per $1,000 of research equipment	$35.83	$31.86

*Based on institutions' FY1988 R&D expenditures in engineering.

Note: Percentages may not add to 100 because of rounding.

SOURCE: National Science Foundation, SRS

Other than these expected differences in program size, however, most instrumentation-related characteristics of the top 20 institutions also applied to the smaller engineering research programs as well. For example, the distribution of equipment-related annual expenditures among the various categories of

[16] NSF 89-326, p. 105.

equipment purchases, maintenance, and operation was essentially the same for the smaller programs as for the largest engineering institutions (e.g., both spent about two-thirds of the total on equipment purchases and one-third on the combination of equipment maintenance/repair and operation). Also, equipment in the two types of institutions was similarly distributed by location (departments versus specialized nondepartmental facilities) and by age and price range, and the two types of institutions had similar average numbers of research users per system, similar relative levels of equipment maintenance costs, etc.

In these indices of the allocation and organization of equipment-related resources, the differences between the best equipped institutions and those with smaller research programs are not nearly as pronounced in engineering as was seen earlier for computer science.

On qualitative assessment measures, however, department heads in the largest engineering institutions were more satisfied with their instrumentation situations than those in institutions with smaller engineering research programs, on average. Thus, engineering department heads at the top 20 institutions relatively often assessed the adequacy of their current research equipment as adequate or better (73 percent versus 54 percent), reported that the adequacy of their equipment had improved over the last three years (61 percent versus 48 percent), reported that the amount of their research equipment had increased over the last three years (81 percent versus 65 percent; Table 23). On balance, however, the magnitude of the differences between the largest and the smaller research performers was not nearly as great in engineering as in computer science.

APPENDIX A
LIST OF SAMPLED INSTITUTIONS

INSTITUTION SAMPLE

Brown University
California Institute of Technology
Colorado St. University
Cornell University
Duke University
Georgia Institute of Technology
Harvard University
Johns Hopkins University
Louisiana State University
Massachusetts Institute of Technology
Michigan State University
Mississippi State University
New Mexico Institute of Mining & Technology
North Carolina State University
Northeastern University
Northwestern University
Ohio State University
Oklahoma State University
Oregon State University
Pennsylvania State University
Princeton University
Purdue University
Rockefeller University
Stanford University
Stevens Institute of Technology
Temple University
Texas A&M University
Texas Tech University
University of Arizona
University of California at Berkeley
University of California at Davis
University of California at Los Angeles
University of California at San Diego
University of Central Florida
University of Colorado (Boulder & Denver)
University of Connecticut
University of Dayton
University of Denver
University of Illinois
University of Iowa
University of Kansas
University of Maryland
University of Michigan
University of Minnesota
University of Nebraska
University of North Dakota
University of Oklahoma
University of Pennsylvania
University of South Alabama
University of Texas
University of Washington
University of Wisconsin
Virginia Polytechnic Institute
Washington State University
Yale University

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